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Quarterly Technical Summary

Educational Technology Program

15 June 1972

Prepared for the Department of the Air Force
and the Advanced Research Projects Agency
under Electronic Systems Division Contract F19628-70-C-0230 by

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts

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13. ABSTRACT

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Work has begun on preliminary designs for LTS-4, which will be a stand-alone system suitable for remote site operation. Major emphasis has been on (1) a new reader system design, (2) specifications for a self-processor, and (3) studies of the audio channel as it affects the storing of digital control information on lesson fiche.

14. KEY WORDS

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15 June 1972

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EDUCATIONAL TECHNOLOGY PROGRAM

I. EDUCATIONAL DEVELOPMENT PROGRAM FOR LTS

A. First Results of Keesler Trial

The basic goal of the Keesler trial of the Lincoln Training System (LTS) is to demonstrate that learning is more rapid than in a regular classroom, with no concomitant loss of effectiveness and with greater student acceptability. Training for one week of Basic Electronics with lessons prepared by Keesler Technical Training Center (KTTC) instructors began on 12 April 1972. The five-terminal system performs very reliably, and thirty students have completed the week. The main results are:

(1) Scores of the LTS group on the Block Test are slightly better than those for control students in the regular class.

(2) Average time to complete 30 hours of classroom work is 18.6 hours.

(3) Responses to an attitude survey indicate strong student preference for LTS over conventional training.

It is expected that further savings in time will be realized through improvements in the lesson material and streamlining of classroom procedures.

B. Cost and Benefits

The LTS was originally proposed as a means for reducing the cost of technical training in the Air Force. The results of the Keesler trial to date confirm the benefits to be derived from automated instruction of this sort and supply a computational base for estimating potential direct dollar savings.

Basic Electronics is a nominal 18-week course which serves as an introduction to more specialized training in one of various classes of equipment – computers, avionics, ground radio, etc. These advanced courses vary in length from 10 to 20 weeks. To take a particular example, ground radio communications equipment repairman training (3ABR 30434) presently requires 36 weeks of resident training; annual input is approximately 1800. The yearly cost to the Air Force, including salary and subsistence for students, is $29,548,800.

Full-scale employment of the LTS (300 terminals) could produce annual savings of $11.2 million. This is derived from reduced training time alone; it does not include savings that might be realized by reduction in the number of instructors or less direct benefits accruing from earlier productive employment of students.

C. Further Performance Data Analysis

Detailed performance data, collected on-line from each Keesler student, are being analyzed at Lincoln Laboratory with the Reckoner, a library of array-handling programs which runs on the CP/CMS time-sharing system.

At present, we are focusing on the development of behavioral norms for each lesson. Our goal is to provide the instructor with a convenient, objective basis for appraising the progress of the individual student to facilitate the discovery and remediation of specific student difficulties.

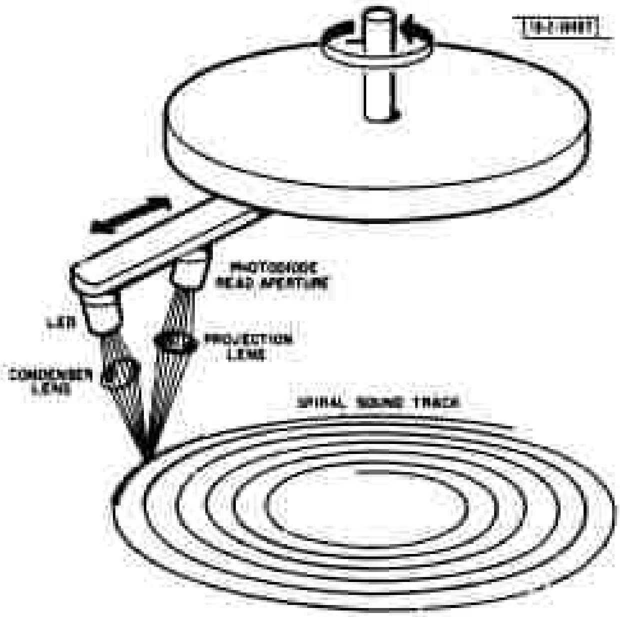

Fig. 1. Reflection reader.

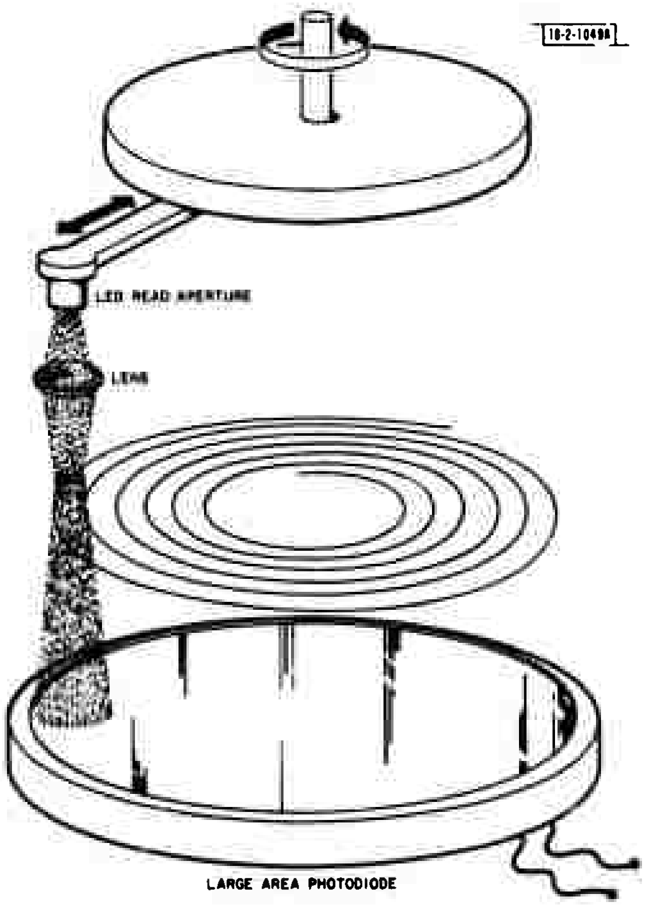

Fig. 2. Transmission reader.

Each lesson is being calibrated in terms of average student performance. There are two measures: the number of frames, and the time he spends studying them, each recorded in up to ten separate areas per lesson. For example, the lesson on series resonance has eight areas, each subserving a lesson objective. They were designated by the author: (1) characteristics of resonant circuits, (2) determination of resonant frequency, (3) determination of the circuit condition at resonance and above and below it, (4) vectors, (5) determination of the bandwidth of resonant circuits, (6) definition and determination of circuit Q, (7) determination of the bandpass of resonant circuits, and (8) selectivity and sensitivity. Whenever a student exits from the lesson, a short printout that gives both the number of frames and the study time for each of these areas is delivered to the instructor. The norms we develop will consist of group performance profiles with which individual printouts can be compared.

II. LTS-4 HARDWARE DEVELOPMENT

During this quarter, the hardware development effort shifted to the preliminary design phase of a stand-alone terminal system (LTS-4). This system will have essentially the same operating features as the LTS-3, but it will not be dependent on a central computer for control, and it will handle microfiche cassettes (containing approximately 30 cards) instead of a 780-card carousel. This will permit use at remote field locations, on board ship and in other non-classroom environments. Such a development implies a self-processor and the storage of program branching logic as well as audio and video information on each frame of the microfiche.

The development of a new audio reader will have as a design goal a simple tracking and positioning system having the high reliability required for deployment in remote areas. The audio channel will be improved by means of a compandor and by using automatic volume control during recording. Other developments will include the design of a demodulator to extract the branching logic from the audio channel, an investigation into high-resolution black and white and color film, and the development of a self-processor.

A. Reader System Development

The recorded audio/data format and density of the LTS-4 microfiche is tentatively assumed to be the same as the LTS-3 microfiche; therefore, acquisition, track, and reproduce requirements are the same. We will, however, implement design features which improve tracking performance and reduce the channel incidental AM. Three basic reader system designs are presently being considered: a reflection reader, a transmission reader, and an opto-mechanical image rotator reader (Figs. 1, 2, and 3).

The reflection reader system (Fig. 1) employs a pulsed IR light emitting diode (LED) on a polar coordinate, horizontally mounted, servo platform to illuminate a "small" region of the spiral sound track. This region is optically imaged onto a shaped-aperture photodiode (similar to the LTS-3 diode) to develop audio and track error signals.

The transmission reader (Fig. 2) is similar to the reflection reader, but the read and track apertures are located on the LED device and optically imaged onto the spiral sound track. Transmitted light is collected by a large-area photodiode, or a condenser/diode system.

The image rotator system (Fig. 3) would employ a Dove prism to rotate the spiral image and would eliminate the need for electrical slip-rings on the rotating platform. This would also tend to simplify the radial track mechanism, since it would not be on the rotating platform.

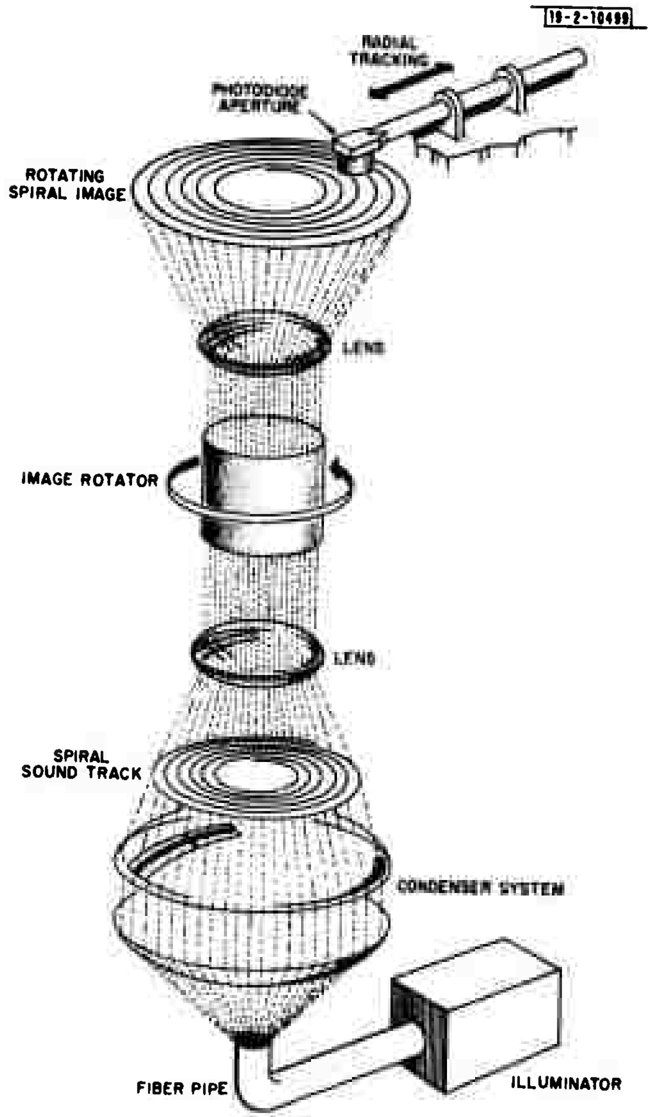

Fig. 3. Image rotator reader.

Study of the above reader configurations has begun. Initial analysis of the reflection approach indicates that it is limited by not only the high reflection loss but available LED radiance. If the read aperture is located on the LED and the photodiode acts merely as a radiation collector, the LED requirements may be more severe.

In either case, the high loss due to reflection can be eliminated if a transmission configuration is used. This relaxes source requirements but requires acceptable uniformity in the large-area photodiode.

A possible electromechanical device for the radial drive element of the reader is the bender bimorph, a device consisting of a sandwich of two slabs of oppositely polarized piezoelectric material such as $PbZrTiO_3$ separated by a thin brass vane. When mounted at one end, in diving board fashion, an applied voltage results in a deflection of the free end. The device has been characterized through a set of measurements and it has been concluded that the required deflection for radial tracking cannot be realized. The device may be of use, however, as a vernier corrector in the radial drive or elsewhere.

The basic requirements for a horizontally mounted polar coordinate servomechanism has been studied with respect to required bandwidths due to imprecise frame registration.

Study of the above system configurations and others will continue for several months, and breadboard models will be constructed to test feasibility.

B. Microfiche Selector Development

The fiche selection subsystem must provide rapid frame and fiche changes and establish precise registration of the audio spiral sound track. A survey of commercial microfiche terminals indicates that only a few have servo-controlled fiche extraction and frame registration. None provides the level of precision required for extracting audio and data information from the LTS-4 spiral recording. However, one system is available which handles 30 cards in a microfiche cassette, and we are evaluating this system to determine whether it, or some of its features, satisfy LTS-4 fiche handling requirements.

C. LTS-4 Self-Processor Development

During this quarter, a survey was made of memory systems that could be used in an LTS-4 self-contained digital processor. The memories were divided into two categories: random-access read/write (RAMs), and read-only memories (ROMs). Included in each category were magnetic core storage systems and both MOS and bipolar semiconductor arrays. A capacitive memory storage system was included in the ROM category.

In the RAM survey, an 18-kilobit, random-access memory configured as 1024 18-bit words was used as a base for comparison. With ROM systems, 16-kilobit configurations were used as a base.

Comparisons were made on cost per bit of a single system as well as quantity of (100), power requirements, speed, physical size, volatility, and TTL compatibility. The results of the comparisons are listed in Tables I and II. The RAM cost columns of Table I reflect both the cost of the memories and their required power supplies. For a more meaningful cost comparison of the semiconductor ROMs, the cost columns of Table II are based on cost per bit of the individual IC chip arrays that would be used to assemble a ROM system. These costs do not include the array masking charges which, depending on the alterability of the ROM, vary considerably. Except where noted, the specifications shown for each memory category are average figures of three to four manufacturers of similar systems.

TABLE I

COMPARISON OF SEMICONDUCTOR AND MAGNETIC CHARACTERISTICS FOR AN 18-KILOBIT RANDOM ACCESS MEMORY

	RAM Type	Magnetic Core	MOS	Bipolar
UNIT CELL	Readout typical	DRO	NDRO	NDRO
	Access time (nsec)	300 to 600	900 to 1500	50 to 100
	Standby power (μW)	0	50	5800
ARRAY OF CELLS	Typical array size (bits)	1K × 9*	256 × 1	16 × 4
	Drive voltages	+5V, +12V	+5V, −12V	+5
	TTL compatible	Yes	Yes	Yes
	Packing density (bpsi)	66	240	100
	Volatility	No	Yes‡	Yes
18-KILOBIT MEMORY 1024 × 18	18-kilobit module size	1K × 9 2 each	1K × 18 1 each	1K × 9 2 each
	Power dissipation (mW/bit)	5.5	2.3	4
	Full cycle time (nsec)	900 to 4000	900 to 1750	50 to 100
	Unit cost (cents/bit)†	9.2	5.3	14
	100 quantity (cents/bit)	7.6	4	13

*Minimum size for plug-in module type.

† Includes power supply cost of 1 to 2 cents per bit.

‡ May be overcome with live-store battery pack option.

TABLE II

COMPARISON OF SEMICONDUCTOR, MAGNETIC, AND CAPACITIVE READ-ONLY MEMORIES

ROM Type	Magnetic Core	Bipolar ROM	Bipolar PROM	MOS ROM	MOS PROM	Capacitive PROM
Access time (nsec)	75 to 100	60		600		100 to 300
Typical array size (bits)	1 K × 16	256 × 4	128 × 8	256 × 8		1 K × 20 or to customer specs
Drive voltages	+5V, +12V	+5V		+5V, −9V		+5V
TTL compatible	Yes	Yes		Yes		Yes
Packing density (bpsi)	111	960		1920		150§
16-kilobit module size	1 K × 16 1 board	16 chips		8 chips		1 K × 16 1 board
Power dissipation (mW/bit)	4	0.5		0.3		Typical 20 μW/bit
Unit cost (cents/bit)	7	2.4*	14†	1.2*	4.6‡	4¶
100 quantity (cents/bit)	5.3	1.4*	8.3†	0.9*	3.1‡	1.5
Content alterability	Field	No	Field or factory	No	Field or factory	Field or factory

* Average $600 cost for each different kilobit program mask.

† Approximate cost of $1000 for programmer hardware to field program bipolar PROMs. Factory program cost $25 for first kilobit chip and $10 per following copy.

‡ $400 cost for printed circuit module to be used with ASR-33 teletype for field altering PROM contents.

§ Includes space for required support electronics.

¶ Cost based on typical 20-kilobit memory. Average 1 cent/bit charge for original content artwork. Factory altering approximately 0.2 cent/bit.

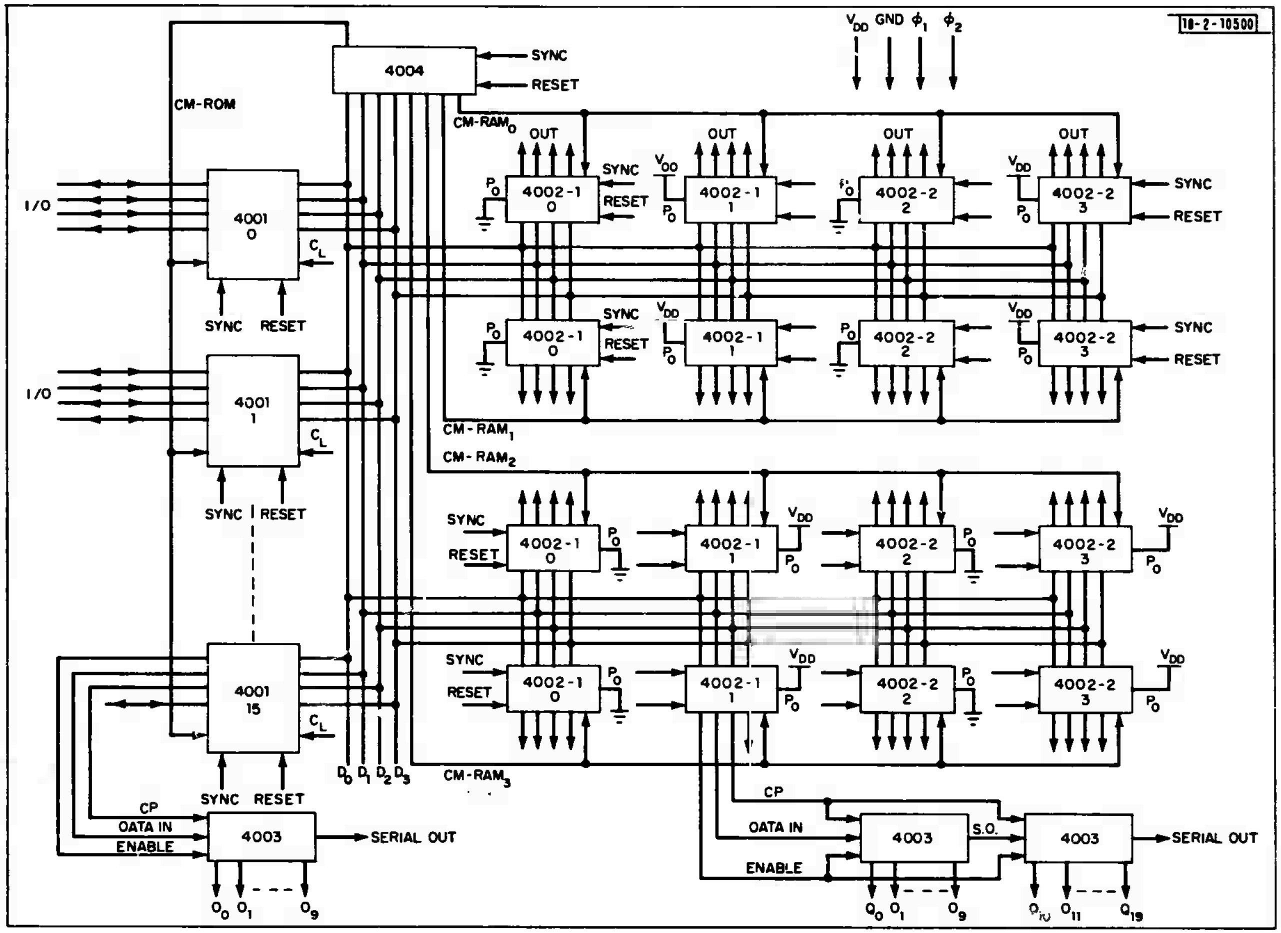

Fig. 4. MCS-4 Micro Computer System.

The above memory survey showed that, for small physical size and low cost (two important requirements for application in an LTS-4 processor), MOS devices would be the logical choice for a processor memory system.

The function of an LTS-4 terminal processor will be to direct and control audio and video presentations at its terminal, in response to student keyboard inputs, conditioned by lesson frame branching logic associated with each frame of data. The LTS-4 processor will in effect be a small, general-purpose, microprogrammed computer with a fixed set of subroutines dedicated to a set of I/O control tasks.

Intel Corporation of Santa Clara, California has developed the major components required to build an LTS-4 digital processor. Their Micro Computer Set (MCS-4) is made up of the following four chips, each packaged in a 16-pin DIP package:

(1) Central Processor Unit (CPU), Intel 4004
(2) Read Only Memory (ROM), Intel 4001
(3) Random Access Memory (RAM), Intel 4002
(4) Shift Register Chip (SR), Intel 4003

Some of the features offered by the MCS-4 are:

4-bit parallel CPU with 45 instructions

Decimal and binary arithmetic modes

10.8-μsec instruction cycle

Sixteen 4-bit general-purpose registers

Nesting of subroutines up to three levels

Instruction set includes conditional branching, jump to subroutines, and indirect fetching

Direct compatibility with ROM and RAM chips

No interface circuitry to memory and I/O required

Directly drives up to: 4K × 8 ROMs, 1280 × 4 RAMs, 128 I/O lines (without 4003), unlimited I/O (with 4003)

Single power supply (V_{DD} – 15 V)

P-channel silicon gate MOS

The CPU contains the control and arithmetic units of a general-purpose microprogrammable computer. This would perform all control and data processing functions of an LTS-4 processor. The ROMs would store microprograms (terminal subroutines) and data tables with the RAMs handling the I/O data and program instructions. The shift register chip (4003) is used in conjunction with I/O devices to effectively increase the number of I/O lines. These would probably not be required in an LTS-4 processor. An MCS-4 system would communicate with terminal hardware through I/O "ports" provided on each RAM and ROM.

A block diagram of an MCS-4 system utilizing 16 each of the RAM and ROM chips is shown in Fig. 4. As noted on the figure, the system is made up of 36 (16-pin) DIP packages which allow 32 kilobits of ROM and approximately 5 kilobits of RAM storage. The 36 chips could easily be accommodated on a $4\frac{1}{2}$- × 5-inch printed circuit board.

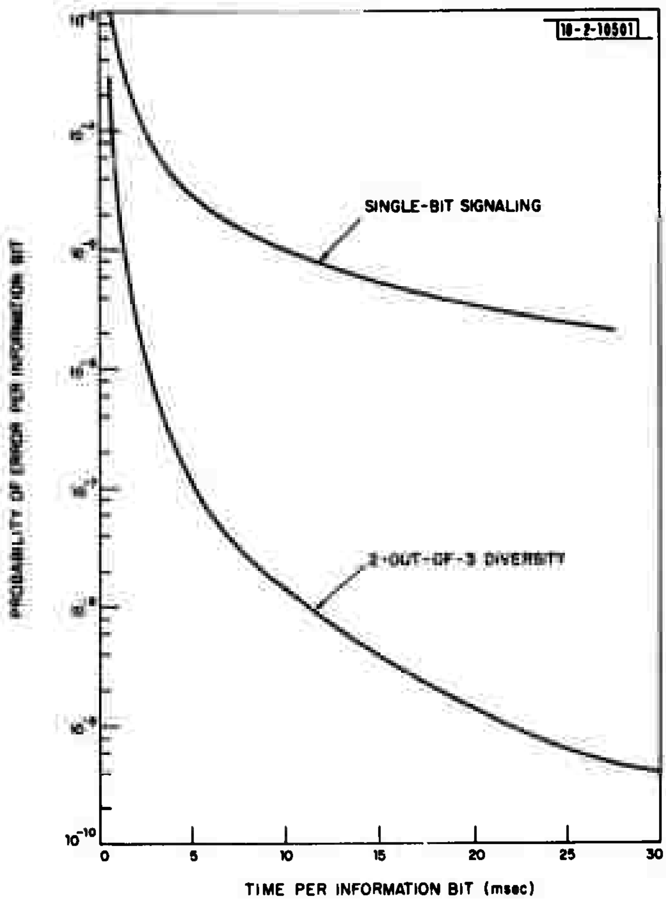

Fig. 5. Upper bound on bit error rate.

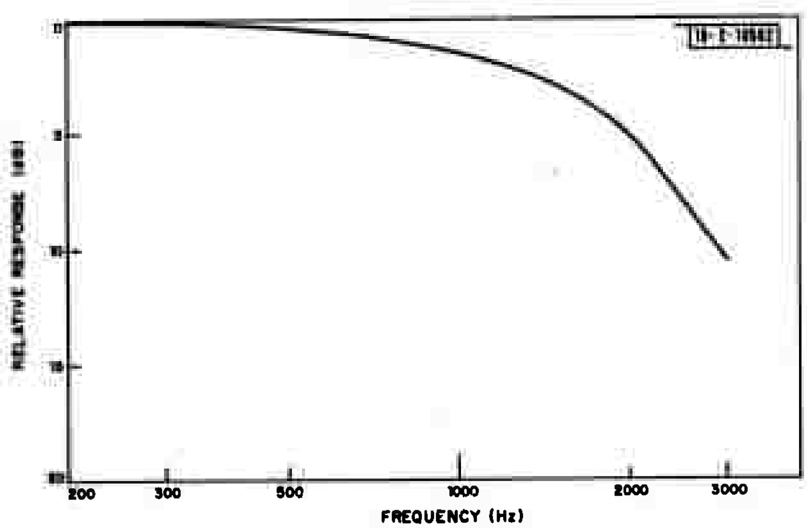

Fig. 6. LTS-3 uncompensated frequency response.

Elements of a Micro Computer System will be procured during the next quarter, and a simulation of the LTS-4 processor will be implemented. Author language program code (LTL), presently used in the LTS-3 system, will be modified to operate in this system, and a digital interface between the processor and the LTS-4 terminal hardware will be developed.

D. Data Modem Development

To provide lesson logic (branching information) for the LTS-4 self-processor, it is necessary to store data on the fiche. The approach that has been chosen for LTS-4 is to record the data at the beginning of the audio spiral and to read out the data when a frame is accessed, before playing the voice message. In order to minimize the audio delay, the data must be made available as rapidly as possible, subject to the constraints imposed by the channel noise, bandwidth, and incidental FM.

The LTS channel is subject to multiplicative impulsive dropouts due to dust, lint, and scratches. The type of disturbance of concern to data transmission is larger in area although much less frequent in occurrence than the typical background audio impulse noise. For example, particles of size 150 μm (corresponding to a transmission rate of 500 bits/sec) have been observed to occur with a probability of 10^{-4}. As another example, error rates of 10^{-3} have been measured using a standard FSK telephone line modem at 1200 bits/sec. On the basis of these preliminary measurements, we plan to use time diversity to counteract large area film defects. In Fig. 5, an upper bound for the bit probability of error is shown for both single-bit signaling and 2-out-of-3 time diversity. These bounds are based upon particular size measurements made on microfiche cards which had been operated in an LTS-3 terminal for several days. It can be seen that, for data bit rates of less than 400 bits per second (1200 bauds/sec), error rates of less than 1 in 10^6 can be achieved.

Although it is difficult to define the bandwidth necessary for data transmission precisely, for the purposes of the present discussion we assume simply that a sinusoid of duration T_b for a frequency f_b will be passed with negligible distortion by an ideal filter with pass band $2f_b$. In Fig. 6, the uncompensated frequency response of the LTS-3 channel is shown. The 3-dB bandwidth is 1500 Hz, and a maximum signaling rate of 750 bauds/sec can be easily accommodated. This maximum rate can be accomplished using phase shift keyed (PSK) signaling which is the proposed data modulation form.

It is interesting to compare the costs of typical telephone line modems as a function of bit rate in that our channel is roughly comparable in bandwidth to that of a telephone line. A typical cost curve is shown in Fig. 7. Costs increase substantially at data rates greater than 1200 bits/sec. From this we infer that the cost break point for the LTS channel occurs somewhat below 1200 bauds/sec.

In order to implement burst error correction schemes, reasonable bit and character synchronization must be effected. For PSK transmission, the timing signal can be derived directly from the data signal by squaring and phase locking. The channel incidental FM causes the phase-locked loop to be more susceptible to loss of lock when multiplicative dropouts occur. To hold within the linear region of the loop phase error detector, phase error must be less than 30°. In Fig. 8, the maximum allowable percent FM is plotted vs the burst error duration to insure loop errors of less than 30°. For a 3-baud diversity system, the timing should be unaffected by a 3-baud burst error; otherwise, the system is no more reliable than a single-bit signaling system. This results in an upper limit of 1.4 percent on the magnitude of channel incidental FM.

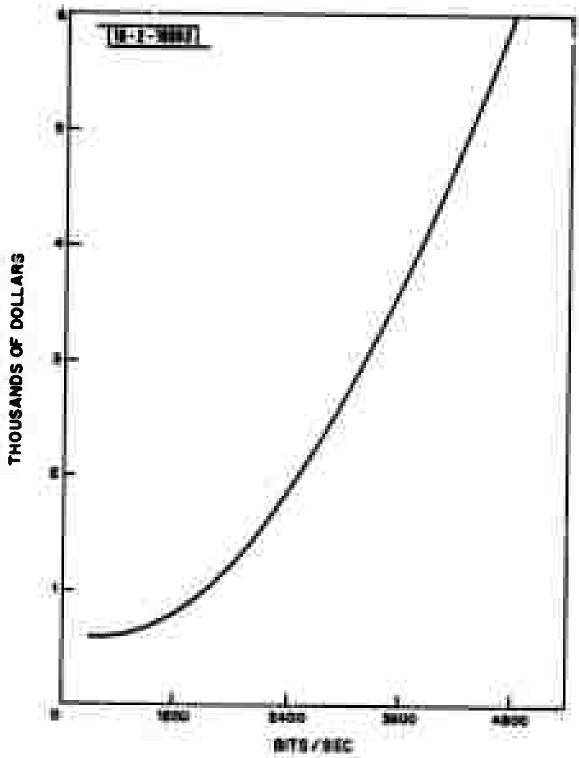

Fig. 7. Cost for typical telephone modems.

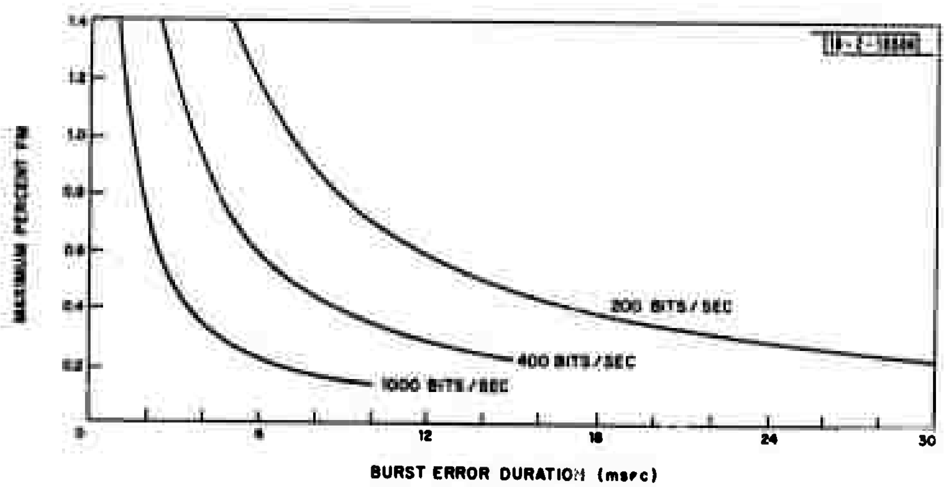

Fig. 8. Maximum percent FM to insure synchronization.

In consideration of these constraints, a PSK 2-out-of-3 diversity modem will be implemented, since it is a reasonable candidate for a final version modem, and will also provide a flexible measurement tool for the current LTS-3 audio channel. Data will be recorded at several signaling rates, and data error statistics will be measured. The results obtained will be used to guide the design of the LTS-4 modem. As an additional feature, the experimental modem will be used to demonstrate a test lesson with the author branching logic on film. Based on the preliminary analysis, the operating data rate of the modem will be 200 to 400 bits/sec.

E. Audio/Data Channel Noise

The LTS-3 experience has indicated that, while the signal-to-baseline Gaussian noise is acceptable (+37 dB), the impulsive noise due to dust and scratches is disruptive. The effect of reducing the recording density on impulse amplitude has been analyzed and measured, and the result is shown in Fig. 9. Although there is some advantage to be gained by decreasing the density, the desire to maintain at least twelve frames per microfiche has motivated studies in speech processing to reduce the impulse noise.

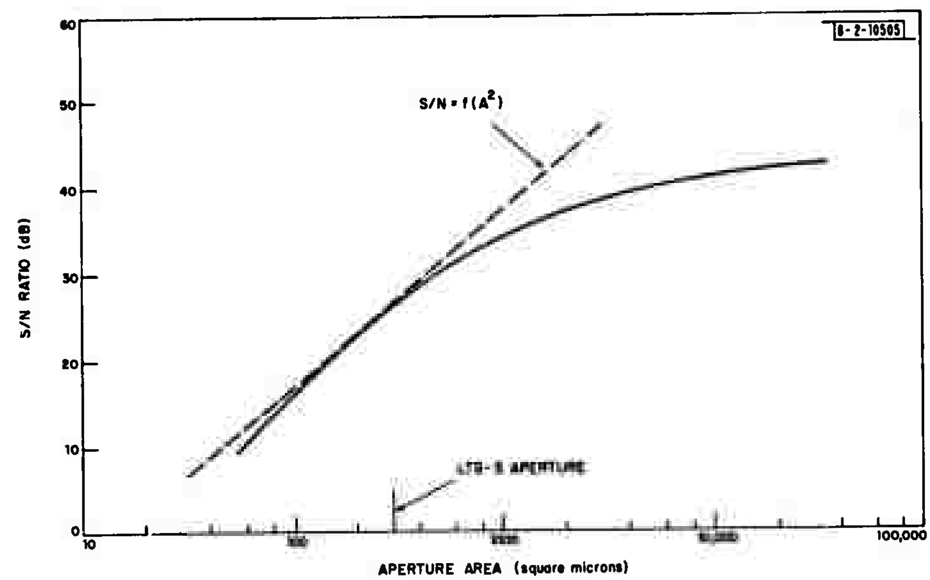

Fig. 9. Signal-to-peak-impulse noise vs aperture area.

To reduce background impulse noise, a syllabic rate speech compressor and expandor (compandor) has been designed for use with the LTS audio channel. A simple block diagram showing the compressor and expandor principle is shown in Fig. 10. The compandor shown gives a 2-to-1 compression and a 2-to-1 expansion in decibels. If the bandwidth of the detector low-pass filter is of the same order of magnitude as the syllabic rate of speech (a time constant on the order of 10 msec), the speech quality is unaffected. In the case of high initial signal-to-noise ratio into the expandor, the output signal-to-noise ratio is essentially unaffected when the signal is present but is substantially increased when the signal is absent. Impulse noise which occurs when the speech is absent is most distressing to the listener, and the expandor reduces this noise to a low level.

For the LTS-3 channel, the rms output noise is due primarily to impulse noise which is +10 dB referred to the rms grain noise. The average output noise, which determines the gain of

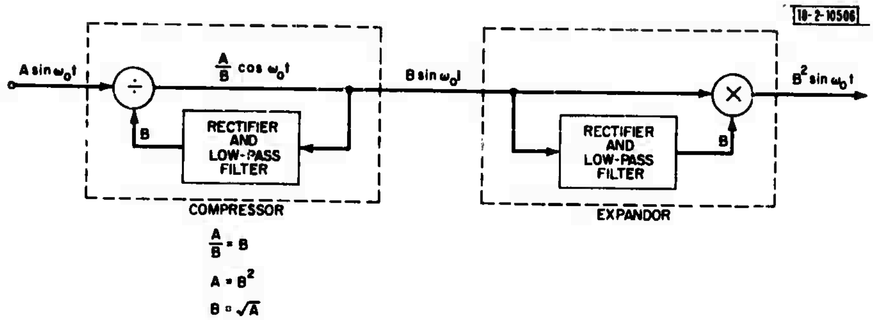

Fig. 10. Compressor and expandor.

the expandor, is due primarily to the grain noise, since the average impulse noise is approximately −10 dB referred to the average grain noise. Hence, the rms expandor output noise should be lowered by an amount equal to the input rms signal-to-grain-noise ratio (37 dB). A measurement was made on LTS-3 with and without expansion. The improvement in signal-to-noise was found to be 34 dB (from +27 dB to +61 dB).

An automatic volume control (AVC) has been implemented as part of the LTS-author recording facility to regulate the audio level of each author to insure that all voice levels will be prevented from exceeding the peak level of the film recorder, while at the same time the voice levels will be prevented from falling into the background noise level of the LTS-3 during playback. The recording experience of the LTS-3 experiment indicated that level variations tended to be as

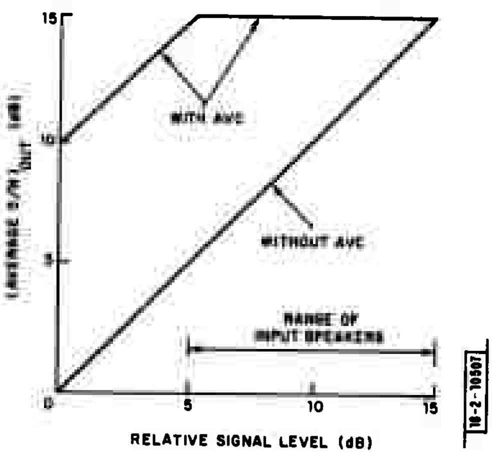

Fig. 11. Signal-to-noise out with AVC.

much as 10 dB even for the same author on the same fiche. The level control problem is particularly acute for LTS-3, since the average signal-to-rms-noise ratio is only +15 dB for a fully modulated speaker. Level control was accomplished by introducing a moderate amount of peak clipping which results in some distortion. The signal-to-noise output is shown in Fig. 11 for the case of AVC and no AVC. The average improvement over a ±5 dB speaker range is 5 dB, which is almost the equivalent of quadrupling the film area.

F. Film Development

The need for stable, high-resolution, inexpensively reproduced microfiche film for the LTS-4 system has resulted in the initiation of a comprehensive study of master and copy films.

Processing equipment is also being studied with the object of identifying the configuration of an optimum fiche production facility.

A number of training subjects would be significantly enhanced if color images could be presented to the student. Consequently, a study is in progress to determine the feasibility of recording color images and spiral sound tracks on a production basis with acceptable quality. Although color film presents relatively low resolution to a microfilm system, the recording of the spiral sound tracks may be possible by the exposure of one of the three color layers which have, separately, higher resolution.

III. LTS-3

The five-terminal prototype system has operated in support of the Keesler trial throughout this quarter. Instructional delays caused by system failures have been minimal (less than one terminal hour per week). The principal causes of failure to date have been the magnetic tape digital I/F unit and microfiche card damage due to film curl. Timing problems in the digital I/F unit have been corrected, and the silver halide film has been replaced by Type 16 Kalvar film to eliminate film curl problems. The only system down time reported since mid-May was the result of radio frequency interference (RFI) caused by a local high-power search radar system which interfered with the magnetic tape unit read electronics. Reducing the final amplifier output power and installing sector blank switches relieved the RFI problem. System failure statistics will be reported in the next quarter, after the end of the Keesler trial.